PRELIMINARY VERSION OF APPLICATION FOR N.S.F. GRANT:

DEVELOPMENT OF INCREASED PROGRAMMING CAPABILITY IN ELECTRONIC ENVIRONMENTAL ART

Yale University
New Haven, Conn.
School of Art and Architecture
Department of Art

Principal Investigators: Peter Kiedlman, Ph.D., Director of Engineering and Applied Science Lab
787-3131 Ext. 583

Dean Howard Weaver, B.A., Dean, Yale School of Art and Architecture
772-0880

Proposed Starting Date: September 1, 1968
Alternate Starting Date: December 1, 1968

TABLE OF CONTENTS

ABSTRACT OF PROPOSED RESEARCH

After two years of research into programming light and sound for environments, we have developed a medium for artistic expression dependant upon electronic technology. Traditional art forms have suffered an increasing separation from our culture's vocabulary of immediate experience; our work has dealt with direct programming of those physical energies--light and sound as opposed to image or melody--through which perception itself occurs, thereby enabling us to stimulate and abstractly shape an elemental physiological experience. The formal structure of such art consists of the storing and retrieval of information over time, a prodedure for which electronic processing techniques are ideally suited. As a first step in developing an evolutionary electronic processing system, we designed and built an analog-digital programming device (synthesizer). As a transitional stage we are hoping shortly to incorporate a multi-track magnetic tape deck which will allow long term, continuous transitions within a given program. However, even with such improved storage possibilities, this stage of our system necessitates manual programming by patch cord and potentiometer. To eliminate these restrictions and also to increase greatly the efficiency and coherence of our programming procedures, we need a system for automaticelly interconnecting module inputs and outputs, either by small digital computer or at least a source of stored program information (punched paper tape).

[This text has been word-processed in 2014 to replicate the illegible original.]

NARRATIVE

I Introduction

This introductory statement presents aesthetic aspects of our project and related art historical material within an otherwise wholly technical paper.

The formation of our research group resulted from numerous discussions and interactions over a period of several years while we were graduate students in art at Yale. During this time, 1964-1967, developments in the contemporary art world influenced our thinking.

1. Those artists whose work stayed significant deals increasingly with the provocation and formal manipulation of direct experience, an approach which rejects image, melody and other referential constructs, and substitutes physiological abstraction. The evolving work of the following artists was typical: the paintings of Pollack, Louis, Noland and Stella; the sculpture of Judd, Andre and Morris; the electronic music of Reich, Young, Reilly, and Cage, the rock music of the Grateful Dead; the writings of Robbe-Grillet, Borroughs and Smithson; the films of Kubelka and Conner.

2. At the same time, new categories of artistic expression were being developed through an increasing awareness of aesthetic potentialities of any experience. As a result, art forms could be seen as extending outward to encompass all media and their combinations in the total environment. Early instances of such environmental art are the work of Kaprow (Happenings), Megan Terry (Open Theatre), and Carolee Schneeman (Dance).

3. Art showed potentiality for becoming more meaningful to our culture by reflecting the accumulating body of experiential information regarding complex human sensibilities being brought into existence and developed by technology. In particular, human perception has undergone evolution through exposure to a variety of technological phenomena, for example, high speed content change, multiplexing, and audio-visual synchrony (television, film). An art form which included these phenomena seemed likely to yield a complex, internally direct experience by calling into play areas of perception constantly invoked in contemporary life, but not in previous art.

Organized as a group of five artists and two engineers in 1966, we set out to make works of art articulating the new human environment through the use of the technologies of information processing. Because light and sound are readily programmable through electronic means, and because they constitute an elemental source of experience capable of tremendous complexity as abstract information, we choose them as our principal medium. We anticipated the need for a period of extended research, and therefore accepted Yale's offer to associate our project with the school as post-graduate research.

We found that current work using light and/or sound broke down into three main areas:

1) Objects—either pieces fabricated by materials-oriented artists who centered their pieces on the inclusion of light and sound as a new material, or else light paintings or light sculpture which maintained the spectator-object relationship essential to traditional art.

2) Psychedelic—a variety of theatrical light show utilizing a set of established procedures including simultaneous projection of slides and liquid images, intended to simulate hallucinations through stereotyped visual images.

3) Special lighting and sound effects in theatrical presentations—varied and often interesting applications of light and sound to embellish or dramatize relationships between audience and actors.

None of these works showed concern for the development of a new art form dealing with the full potentialities of our technological environment. On the other hand, the work of Flavin and Turell, who deal exclusively with non-programmed light, and USCO who make use of a generalized, meta-symbolic multi-media seemed promising, but were actually unrelated to an art committed to abstractly programming the physiological energies of perception.

We began our work in programmed light and sound environment with a series of experiments (1966-1967) in a loft using manually regulated oscillators, cycling timers, filters, mixer, and light modulators to activate assorted light and speaker configurations. To maximize the perceptibility of the field aspects of light we painted the loft white and expanded it with stretched silver mylar reflectors. Noting their capability for complexly patterned, instantaneous response, variable by both frequency and amplitude changes in control signals, we selected banks of fluorescent bulbs as principal light sources. Programs of sound and light were recorded on several channels of magnetic tape and presented to various audiences.

In December, 1967 Yale invited our group to design a large scale programmed environment for the gallery of the School of Art and Architecture. Our outputs for this environment were one thousand fluorescent bulbs, ten loudspeaker channels, eight mylar electrostatic speaker channels, six fluorescent strobe systems, and four electrostatically oscillated mylar reflectors. We also used seven hundred yards of stretched mylar reflectors. The exhibition was financed primarily by donations of materials from twenty-three companies. To program these outputs we designed and constructed the synthesizer described in the next section.

With this system we have realized a series of thirty live-time programs for the public. In developing these programs the realization of the potentialities we designed into our programming device led to a fusion of technological and aesthetic ideas. In order to pursue the natural evolution of this integrative creative process we seek improved programming capabilities.

II. PRESENT PROGRAMMING DEVICE IN ASSOCIATION WITH WHICH INCREASED PROGRAMMING CAPABILITY IS REQUESTED

Introduction:

Studies in sound perception and growing interest in electronic music have led to the development of new approaches to signal synthesis. Digital control of all sound parameters[1] is an attractive approach. Once the necessary computer programs are available, the main advantages consist in: 1) the relatively easy creation of structural complexity, and 2) the exact reproducibility of effects. The cost of such an approach is still high despite recent price breaks. An equally serious limitation lies in the fact that our work in light and sound synthesis requires a large number of simultaneous output channels (10 to 50). The generation of sound electronically by digital computer alone into this many channels is far too complex and expensive to consider at present. We therefore are pursuing an approach involving digital control of the operating parameters of electronic modules which are the actual generators and modifiers of audio information. This implies control on a time scale far slower than the actual cycle-bycycle control over the output waveforms as would occur in direct digital computer synthesis. The control time scale for a modular system in fact lies within the speed capabilities of punched paper tape readers. In section III we describe a system based on this approach.

In terms of our present resources we have developed a system both sufficient in itself and readily compatible with expansion toward increasing programming flexibility. By relaxing the requirement of complete digital control and instead using simple circuits of the analog computer type to perform

1. Journal of the Audio Engineering Society, Vol. 14:1, January, 1966, Arthur Roberts,"An All Fortran Music-Generating Computer Program;" and Robert K. Clark, "A Program for the Real-Time Generation of Musical Sounds."

voltage controlled operations, we constructed at relatively small cost a hybrid modular system which retains many of the advantages of digital control. The instant access to all parameters made possible by such a hybrid system greatly enhances experimental and compositional modes of operation, especially where iterative adjustments are made to obtain the desired signal characteristics. Our present system makes possible not only the simultaneous generation of the 10 or more output channels, but also the easy attainment of sufficiently complex sequencing to generate program cycles of up to 30 minutes in "live" operation.

In subsequent sections we describe the system philosophy of our low-cost modular solid state system and module specifications in brief.

Systems Considerations:

Modular sound synthesis systems utilizing the economy, reliability and compactness of solid-state design are currently manufactured by R.A. Moog Co. in Trumansburg, N.Y., and Buchla Associates of Berkeley, California. These systems represent a great advance over earlier sound synthesizers, but do not as yet incorporate all possibilities of current technology. The design and construction of our present system takes full advantage of existing linear and digital integrated circuits. These devices permit considerable economy of design and wiring time and provide a significant improvement in performance and reliability over discrete component systems. This means that even with modest facilities one can construct with confidence quite complex instrumentation.

The main features of our system are as follows:

A. Voltage Control of all important parameters, such as
   (1) frequency
   (2) amplitude
   (3) attack and decay duration (independently)

(4) time interval generation by means of shift registers and other digital function modules.

The control voltage range is 0 to +3 volts, compatible with the linear and digital integrated circuits used in the design. Specifically, it was chosen to accomodate the logic levels of the RTL (resistor-transistor logic) circuits used. The extensive use of high-gain operation amplifier configurations insures ample stability within this voltage range.

B. Elimination of the distinction between signal and control voltages for maximum compatibility.

The Buchla system, for instance, uses separate modules for signal and control functions. This leads to needless duplication of circuitry. For instance: (1) A "mixer" module will combine audio signals, and another module will combine control voltages. Yet both instances involve simply the addition of voltages, most simply done with an operational amplifier circuit. (2) So-called "ring modulators," basically small-signal analog multipliers, are used to generate beat frequencies, but are not usable to generate the product of control voltages.

In contrast, we aimed at maximum flexibility by designing modules all of which can accomodate frequencies from DC to 20 kHz at up to 3 volt amplitude. The output voltage swing of all "source" modules, such as voltage controlled oscillators (VCOs), is between -3 to +3 volts. The wide frequency range of the VCOs allows them to function as sources of control voltage (in the range of 0.02 to 20 Hz) or as signal sources (in the range of 20 Hz to 20 kHz). Since all modules are DC coupled all circuit functions are independent of frequency. Thus a given VCO operating at a low frequency (say 2 Hz) might be used to frequency modulate another VCO (of identical design) operating at higher frequency, say 1000 Hz. Operational amplifier summers and inverters are used to scale and translate control voltages.

C. Low Impedance Interconnections.

All module output impedance are very low (generally about 0.1 to 1 ohm); all input impedances are in the range of 1000 to 4000 ohms. We have found it unnecessary to use shielded wire for patched interconnections, even in electrically noisy environments (e.g. SCR control circuits in fairly close proximity).

The utilization of simple pin jacks and plugs for all connections between modules also results naturally from our eliminating the distinction between signal circuits and control circuits.

We hope to improve the interconnection scheme by a matrix of reed relays with address logic as soon as possible (see section III). All module inputs and outputs can be brought to the relay matrix from a rear connector on each module. The individual relays in the matrix would be digitally programmed from punched paper tape or magnetic tape.

D. General Purpose Potentiometers.

As a deliberate design simplification no means are provided within a module to manually set a certain parameter; instead it is voltage controlled externally. For manual setting of sound parameters and for general use as amplitude controls, 60 potentiometers are presently provided on the front panel. These can be set individually to an accuracy of 3% of full scale and with a repeatability of 1% of full scale. Despite the use of simple carbon potentiometers, this accuracy is achieved by a technique familiar from analog computers. A DPDT push-button is associated with each potentiometer. Depressing the button places a +3 volt reference voltage across the resistance element while a meter indicates the voltage between wiper arm and the grounded end of the resistance element as a fraction of full scale. Any load on the wiper arm (i.e. the input to a module) is left connected. This allows an accurate setting of the voltage division ratio under actual load conditions. Locating such potentiometers immediately below or above each module allows a

direct association between the two, electrically as well as visually. +3 volts is available on the potentiometer panels to allow any potentiometer to be patched as an adjustable control voltage source.

E. Ability to modify external program material.

While the modular system was designed for flexible "live" signal generation, this very flexibility also offers rich possibilities for modifying external audio material (e.g. taped signals, specialized waveform or noisegenerator outputs or live sound pickup). The "modifier" modules (as opposed to the "source" modules, both to be described shortly) can perform amplitude modulation, beat frequency generation, signal routing, etc. on such external audio material. The combination of live signal synthesis with modified external inputs offers almost limitless possibilities.

F. Generation of time intervals and fixed or pseudo-random patterns by shift registers and other logic circuitry.

Up to 50 shift register stages are provided in the form of 5-stage modules. These can be cascaded or independently operated. In the Buchla system, ring counters are provided which propagate a single "ON-state" around a set of stages. Our shift-register design permits not only such ring counter operation, but more generally the propagation of any pattern of ON and OFF states along a set of stages, whether arranged in an open chain or lieded into a ring. Special shift register configurations (e.g. the so-called Johnson counter) can be used to generate pseudo-random sequences.

In addition, OR and AND Logic curcuits are porvided. Their use in conjunction with different sets of shift register stages allows formulation of timing sequences of great complexity. The shift pulses for shift registers can be obtained from voltage controlled oscillators, voltage controlled clocks (to be described below), as well as from any other shift register or logic circuit.

Module Specifications:

Here follows a brief description of the modules in the system at this time. Additional types of modules will be designed depending on future need, but the present set constitutes a valid nucleus for sound synthesis experiments.

A. Voltage Controlled Oscillators (VCOs).

Ten such circuits have been constructed to date, in five modules. Each can be swept over 3 decades by a control input of 0 to 3 volts. While the basic range is 20 Hz to 20 kHz, external capacitors will allow lower frequency operation. For instance, an external 1 MF capacitor, patched into terminals provided, changes the range to 0.2 to 200 Hz. Both linear and logarithmic frequency control is available. Three output waveforms (sine, triangular, square) are simultaneously available. The output voltage excursion in each case is -3 to +3 volts. From the description of the VCO's circuit (to follow below) it will be seen that the slope of the output waveform is instantaneously proportional to the control voltage. Thus there is no restriction on the frequency content of the control input. For instance, feedback from the square-wave output to the control input will produce controlled assymetry of the output, allowing a type of voltage control of harmonic content in conjunction with a multiplier module (described below).

B. Log Function Generators.

These two-terminal diode-resistor networks are housed in a separate temperature controlled module. Used as series elements feeding a control input summing junction on the VCOs, they provide stable logarithmic voltage to current conversion for logarithmic frequency control.

C. Voltage Controlled Clocks.

This is essentially a kind of special purpose VCO. The output frequency is voltage controlled over the range of about 0.2 to 10 Hz, the available output waveforms are sawtooth and

narrow pulse (both 0 to +3 volts). The latter is intended as a shift pulse for shift registers; the former can be used for frequency sweeps. The effect of a control voltage change on the output frequency is instantaneous (as is the case for the VCOs). This will later be seen to be of great usefulness in conjunction with the shift register modules. Five such circuits are available in one module.

D. Envelope generators.

This unit generates a general purpose trapezoidal waveform for use in amplitude or frequency modulation. The attack (0 to +3 volts linear rise) and decay (+3 to 0 linear fall) durations are independently voltage controllable over the range of 5 sec to 8 millisec. The time intervals between the start of the attack and the start of the decay are determined by a gate input, usually obtained from a shift register stage. The system incorporates ten envelope generators at this time (two per module). External capacitors can be patched in to lengthen attack and decay to 50 or 500 sec.

E. Multipliers.

The multiplier circuits are of the four-quadrant type, with two inputs and one output covering the voltage range of -3 to +3 volts. Simultaneous pulse-height-pulse-width modulation of a 200 kHz square wave was used here, but the method is immaterial since commercial four-quadrant multipliers well-suited for this application are now available for under $150.

Depending on the choice of inputs, the following functions can be performed:

1) Amplitude control (Audio signal x control voltage). In this fashion an envelope generator waveform is imposed on a VCO output, for instance.

2) Beat frequency generation (One audio signal x another audio signal). This process of sum and difference frequency generation is useful for the synthesis of complex signals.

3) Frequency doubling. By connecting both inputs together and squaring a sine wave, frequency doubling occurs. The concurrent DC component can be removed with a coupling capacitor, or offset with an operational amplifier.

4) Manipulation of control voltages. Envelope generator outputs can be squared for parabolic rise and fall, complex envelopes can be generated as the product of individual envelope generator outputs, and so forth.

The fundamental usefulness of the multiplier circuit can hardly be overemphasized. Accordingly, 15 such circuits are at present available, three per module.

F. Operational Amplifiers.

With a total of five inputs, each circuit generates the sum of the input voltages. The inputs are weighted so as to keep the sum from exceeding the 3 volt maximum.

It may be mentioned here that the VCO and the operational amplifier, amongst others, have another control input available in the form of an operational amplifier summing junction. By use of appropriate series resistors (available as plug-in elements) extra summing operations can be performed without the need for another operational amplifier module. The use of high gain amplifiers and precision resistors yields gain stabilities of beter than 1% and output zero drift below 2mV.

G. Inverters.

These have one input, one summing junction and one output available and can be used to convert a 0 to +3 volts transition to one from +3 to 0 volts, as would be needed for cross-fading. Eight inverters are contained in two modules.

H. Linear Gates.

For purposes of signal routing 17 of these bidirectional linear gates were designed into 3 modules. Each gate takes the form of a single-pole double throw electronic switch, controlled by a differential input. A given voltage source can be routed to two inputs or a given input can select from two sources. Again the DC coupling allows either audio signals, control voltages, or digital signals (to be discussed shortly), to be so handled. The gating is controlled by a differential input stage which decides in effect the sign of the difference of two

control voltages anywhere in the range of -3 to +3 volts. The actual switching is done by metal-oxide field effect transistors (MOSFETs). Again, such circuits are now available entirely in integrated circuit form.

I. Shift Registers.

As mentioned above, ten modules are grouped five stages per module. Each stage has individual set and reset inputs and complementary buffered outputs. The inputs to the module as a whole consist of the logical inputs to the first stage (the J and K inputs), a buffered-shift pulse input and a common set-reset input which forces all stages into an ON-OFF configuration chosen by toggle switches in each stage. Inputs and outputs on this and all other digital modules assume only two values, 0 and +3 volts. The shift registers are basic to the operation of the system, providing timing and sequencing functions, but in the interest of brevity only some applications will be given:

1) A certain fraction of the "yes" output from each stage is obtained by potentiometers. These voltages are added by an operational amplifier, the output of which controls the frequency of a voltage controlled clock. The clock's pulse output in turn acts as the shift pulse for the shift register. For simplicity, let the shift register be operated as a 5 stage ring counter (i.e. one ON state propagates around the 5 stages). Immediately following the shift pulse, the new state of the shift register determines the control voltage input to the voltage controlled clock, thus determining the time interval until the next shift pulse. This is possible because of the instantaneous response of clock period to control input.

This arrangement allows independent adjustment of the ON duration of each shift register stage (0.1 to 5 seconds for potentiometer from minimum to maximum. Se description of voltage controlled clock above.)

Other sets of 5 potentiometers, summed by an operational amplifier, can generate stepwise varying control voltages for simultaneously associating a frequency or an amplitude with each shift register state.

2) Timing cycles within timing cycles can be created by using the output from one stage of a

shift register loop as the shift pulse for another loop. These loop connections can be "simple" or "twisted" or more specialized, such as in the "Johnson counter" configuration. The last has usefulness for pseudo-random sequence generation.

3) Linear gates, when driven from shift registers, can generate complex routing sequences for audio signals and control voltages. A given sequence of control voltages, as generated in (1) above, could be used in turn to determine a sequence of frequencies, amplitudes or time-intervals, by routing to a VCO, a multiplier or a voltage controlled clock respectively.

J. Other logic circuits.

The system also contains several modules of AND, OR and NOR circuits. The can be used to "recognize" certain shift register configurations (e.g. for purposes of initiating a new timing cycle), or to set up mutually exclusive shift patterns among the shift register modules.

It should also be recalled that the differential input of the linear gates allows them to make decisions regarding the amplitude relationships amongst the control voltages determining the characteristics of the synthesized signal(s). These decisions can determine the routing of digital or analog signals. The logic circuits and linear gates provide the means for logical decisions among the discrete as well as continuous variables of the system.

The design of additional types of modules such as voltage controlled filters, envelope generators with greater than 500 second rise and fall times, etc. is under consideration to fulfill anticipated needs. It is also planned that our system will shortly be expanded by the addition of one or more multi-channel magnetic tape recorders (at least some channels of which are capable of frequency modulation recording) for the storage of both control voltages and signals.

Output devices:

As further illustration of the nature and application of our system, we include a description of the particular set of output devices used in association with our show at Yale School of Art and Architecture. It should be kept in mind that our programming system is capable of association with all types of light and sound sources through appropriate electronics.

The various output signals from the control system are amplified in remote locations driving a variety of output devices which generate the sensory information.

Standard among the output devices are the hifi speakers, about ten of which are located within the exhibition space. Each speaker is associated with its own amplifier and can function as an independent circuit.

Two other types of output devices deserve description in greater detail because they are essential in creating visual information of a complexity comparable to that possible through speakers.

A. Fluorescent bulb arrays ("lightwalls").

Groups of fluorescent bulbs (usually about 200) are mounted either contiguously or in clusters of three to form light sources distributed over large areas. The enclosed photographs show both arrangements. A total of about 1000 bulbs are used in the space in the form of 5 electrically independent lightwalls.

Standard 8-foot bulbs were individually modified for use in this instance. The resulting arrays are unique in their capability to produce complex light patterns in spite of each array being a two-terminal device.

The bulbs are operated as cold gas discharges (the internal filaments are not heated), with one internal and one

external electrode. The cold filament on one end forms the internal electrode, an aluminum strip around the glass envelope near the other end forms the external electrode. The result is weak capacitive coupling to the discharge tube. About 200 bulbs so modified are all connected in parallel, permitting the use of a simple structural scheme. The pair of wires from each array are fed from special high power audio amplifiers, designed to drive capacitive loads to levels in excess of 5 kV at frequencies from 100 Hz to beyond 20 kHz. The following should help explain the operation of the lightwalls.

1.) No attempt was made to minimize distortion in the driver amplifiers. As a result the signal to the light walls is rich in harmonics, extending to about 50 kHz.

2) At low frequencies the capacitive coupling is very weak, allowing all bulbs to light dimly. At drive frequencies of about 10 Hz (square wave drive) the entire array shimmers faintly. The discharge intensity is not uniform along a given bulb, resulting in flecked patterns.

3) At somewhat higher frequencies, the illumination along each bulb and for all bulbs becomes brighter and steadier. At high enough driving amplitudes all bulbs are on, because the capacitive coupling impedance is still high. As the amplitude is lowered alternate bulbs go out out. We suspect that in this marginal amplitude range the lower longitudinal electric field along an "on" bulb sufficiently lowers the electric field along the neighboring bulbs so as to prevent them form firing, resulting in a "nearest neighbor exclusion principal." At even lower amplitudes only a few bulbs, those with the lowest firing potential, remain on. Pulsing of the driving source at intermediate or low amplitudes will shift the pattern of "on" bulbs randomly within the array. We have found the uniformity among bulbs to be excellent.

4) At high frequencies the point is finally reached where the capacitive coupling impedance is low enough so that only a few bulbs are on, very brightly, thereby lowering the supply voltage across the array

sufficiently to prevent the rest from firing. The pattern is strikingly striated and can again be shifted by pulsing the drive signal.

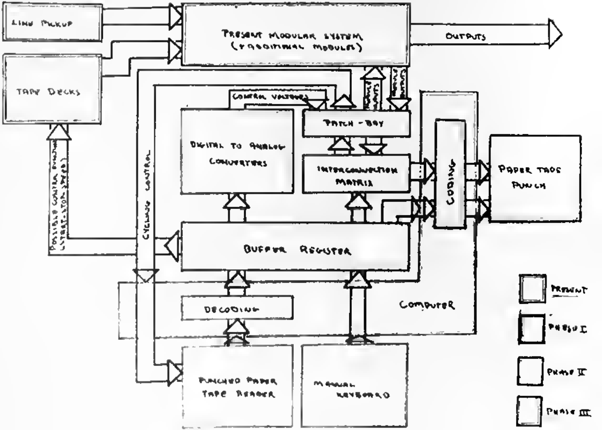
5) Various other modes of operation characteristic of gas discharges can be induced. For example, at intermediate frequencies and higher amplitudes, regular brightness variations along each tube can be made to appear, moving slowly along the tube. This presumably has to do with instabilities in the plasma column.

6) One of the lightwalls has been mounted in close proximity to a ground plane of metallized mylar. This produces an additional striking effect: at low drive the discharge is localized near each end, gradually spreading toward the middle of the tube as drive is increased. At high amplitudes the tube is uniformly lit.

B. Vibrating Mylar Panels.

These were designed to introduce an additional element of optical output. Four x eight foot stretched metallized mylar sheets are driven from a modulated high voltage supply (0.5 to 20 Hz at 0 10 kV) by means of an off-center electrostatic drive element. Off-center placement allows vibration of the lowest, as well as higher-order, modes of the membrane to be excited by suitable choice of driving frequency.

Lowest-order mode vibration (usually about 2 Hz) can be of sufficiently large amplitude to produce "focal lengths" of about 75 feet at the excursion peak. This results in noticeable distortion of reflected images. Intermittent illumination from lightwalls can be synchronized with the with the vibration to produce stationary distortion or generated at a slightly different frequency to produce a very slowly changing distortion. At present four vibrating panels are installed in the space.



LINE PICKUP
PRESENT MODULAR SYSTEM
(+ ADDITIONAL MODULES)
OUTPUTS
TAPE DECKS
CONTROL VOLTAGES
PATCH-BAY
DIGITAL TO ANALOG CONVERTERS
INTERCONNECTION MATRIX
CODING
PAPER TAPE PUNCH
CYCLING CONTROL
BUFFER REGISTER
DECODING
COMPUTER
PUNCHED PAPER TAPE READER
MANUAL KEYBOARD
PRESENT
PHASE I
PHASE II
PHASE III

III. DESCRIPTION OF FACILITIES REQUIRED FOR INCREASED PROGRAMMING CAPABILITY

The principal limitation of our present programming procedure lies in the necessity of introducing program changes by manual repatching and changing of potentiometer settings. This difficulty can be alleviated through a structured introduction of automatic control equipment which sequences module interconnections as well as generates control voltages. Ultimately all control functions should be coordinated by a small digital computer and the necessary interfacing equipment. This would allow the artist to work directly with structural forms, describing in terms of an appropriate program language desired light and sound sequences which are stored in the computer as subroutines. All necessity for "bookkeeping" would be then eliminated in that the artist needs no longer keep track of individual modules or their function.

The expansion of the technical facilities outlined below projects a three phase evolutionary program through which we would move toward the above fully computerized state. The progression outlined is designed to permit meaningful operation at each stage without duplication or obsolescence of equipment of earlier phases by later ones. A diagram of the components of the three phases and their relationship to existing equipment is shown in an accompanying diagram.

Phase I

A.) All module and potentiometer connections would be brought to a patch bay with removable programming boards. Given programs could then be retained and quickly interchanged though pot settings would still be regulated manually. At this stage we would allow copious extra room on the patchbay for reasons enumerated below.

B) We would then incorporate into the system an interconnection matrix of reed relays controlled by digital logic and buffer storage circuitry. The logic circuitry would in turn derive its inputs from a

manual keyboard and punched paper tape reader. Since each reed relay and associated circuitry is likely to cost $5 to $10, not all module inputs (about 200) and outputs (about 100) could be brought under the control of such an interconnection matrix. Bringing all inputs and outputs together in the matrix would in fact not be necessary because 1) certain interconnections between modules could be made fixed without appreciable loss of generality and 2) each program would incorporate fixed and variable constituents so that not all module interconnections need have access to high-speed re-programming made possible by the interconnection matrix.

We therefore propose to make the terminals of the interconnection matrix initially available on the patch-bay mentioned described above. These module interconnections envisioned as remaining fixed during a given program would be assigned fixed patch interconnections; those that need be variable would be controlled by the paper tape reader. A given program could then be retained in the form of a patched program board removable from the patch bay and an associated paper tape.

C.) The need to change module interconnections rapidly is not the only requirement of programming flexibility. The setting of the potentiometers would also be assigned to an automatic control device, at least in part. Toward this end we propose the incorporation of a number of digital-to-analog converters (DACs) into the system. These would also be driven through digital logic and buffer storage circuitry from the paper tape reader. The voltages thus generated would serve as control voltages. A DAC and multiplier combination would form a device with digitally controlled gain--a digital "potentiometer."

Thus the setting of potentiometers would become a hybrid arrangement just like the module interconnections. Certain settings remaining fixed during a given program would be manually preset to recorded values. Other potentiometers would be replaced as such by their digital equivalents, rapidly controllable by punched paper tape. The patch bay would be the means by which these distinct assignments of potentiometer functions would be made.

With the completion of the above components, all of which would be included in Phase I of the envisioned evolution of our system, the fixed and variable parameters of each program

would be determined. The fixed interconnections would be fixed patched on the patch bay, the fixed-pot settings would be made and recorded. The variable parameters would then be patched through the interconnection matrix and the DACs, for which a control tape would be prepared (the digital circuitry mentioned earlier would incorporate the necessary de-coding schemes to permit information on the tape to be associated unambiguously with the making or breaking of matrix connections on the one hand and the setting of DACs on the other). Paper tapes would be prepared on a manual paper tape punch and on existing keyboard paper tape punches available at Yale such as Fridee Flexo writers.

Depending on the experience gained in working with such a system and the availablity of funds, it would be expected that an increasing number of matrix connections and DACs would be made available. As this occurred a number of modules could be permanently assigned to matrix locations and DACs, by passing the patch bay altogether. This would increase the rate at which a given program could be set up considerably.

Phase 2

Because existing paper tape punches at our disposal have idiosyncratic coding which limit their usefulness, and further because such punches are often unavailable for use, the second phase of our scheme would entail the addition of a paper-tape punch and associated coding circuitry. At each stage in the formulation of a program the then existing matrix connections and DAC settings could be coded on paper tape for subsequent playback through the tape reader.

We also envision circuitry which would control the paper tape reader as follows:

> 1) After a block of information has been read into the system and a program section unfolded itself in the operation of the modules, the states of digital modules could be used to establish the end of

the program section.

2) When the end of a program section has been recognized by the modules, the tape reader could be activated to read in the next block of information for the next programmsection.

The degree of retention of logical functions in the form of system modules would be reviewed constantly as the system expanded. It might well prove more economical in many cases to incorporate the logic functions now contained in modules into the rest of the logic circuitry necessary for the operation of the matrix and the DACs.

Phase III

This final phase would involve the incorporation of a small digital computer, mentioned here for completeness, though not intended for immediate acquisition unless financial means become unexpectedly available. The computer would link all input devices (keyboard, tape reader) and output (tape punch , DACs, interconnection matrix). This would permit macroprogramming with subroutines of light and sound information on a maximally flexible level. Since computer programs developed for electronic music composition would almost certainly be unsuitable for experiments in light and sound, the development of suitable programming languages would constitute a major area for future work.

The actual construction of the expanded system as described would utilize commercially available components to the maximum extent possible. In the case of the interconnection matrix, the DACs and other circuitry, commercially available printed circuit cards with integrated circuits would form the building blocks, while their actual assembly into a system would be done by ourselves and in part through existing shop services at Yale University.

BIOGRAPHY OF PRINCIPAL INVESTIGATORS; LISTS OF THEIR PRINCIPAL PUBLICATIONS; LIST OF RESEARCHERS

Peter J. Kindlmann - Principal Investigator

Ph.D. in Engineering and Applied Science, 1966, Yale University; doctoral dissertation under Prof. W.R. Bennett, Jr. on "The Measurement of Excited State Lifetimes."

Associate Director, Engineering and Applied Science Electronics Lab, Yale University: November 1965 to June 1968; Director, July 1968-- (Initial organization of departmental laboratory for the design and construction of research instrumentation, continuing work in the design of electronic instruments.

Research Applied Scientist in the Engineering and Applied Science Department, Yale University: July 1966 to June 1968; Research Associate, July 1968-- (Research: radiative lifetimes of excited atomic states, inelastic collisions, gas lasers).

Lecturer in Engineering and Applied Science, Yale University: July 1966 to present (course: "Topics in Electronic Instrumentation").

Awards:

Kinne Humanities Award, 1960, Columbia College.
National Science Foundation predoctoral fellow: 1962-66.
Honeywell Award in the Department of Engineering and Applied Science, Yale University, 1966.

Publications:

A magnetostrictively Tuned Optical Maser (with W. R. Bennett, Jr.), Rev. Sci. Instr. 33, 601, (1962).

Einstein A-coefficients for Exicited States of Helium (with W.R. Bennett, Jr.) Bul. Am. Phys. Soc, 8, 87, (1963).

Collision Cross-sections and Optical Maser Considerations for Helium (with W. R. Bennett, Jr.), Bull. Am. Phys. Soc. 8, 87, (1963).

Measurement of Excited State Relaxation Rates (with W.R. Bennet, Jr.and G.N. Mercer) Appl. Opt. Suppl., 2, 34, (1965).

Relaxation Rates of the Ar+ Laser Levels (with W. R. Bennet, Jr., G.N. Mercer, and J. Sunderland) App. Phys. Letters 5, 158, (1964).

Tunnel Diode Pulser Measures Cable Delay, Electronics 39, No. 4, 87 (February 1966).

Phase Stabilized Vernier Chronotron (with J. Sunderland), Rev. Sci. Instr. 37, 445 (1966).

Radiative and Collision Induced Relaxation of Atomic States in the $3p^5 2p$ Configuration of Neon (with W. R. Bennett, Jr.) Phys. Rev. 149, 38 (1966).

Direct Electron Excitation Cross Sections Pertinent to Argon Ion Lasers (with W.R. Bennett, Jr., G.N. Mercer, B. Wexler, and H. Hyman), Phys. Rev. Letters 17, 987 (1966).

Voltage Controlled Attenuator, Rev. Sci. Instr. 39, 81 (1968).

Capacitive Detection of Very Small Aquatic Animals (with B. B. Applewhite, and H.J. Morrowitz) Rev. Sci. Instr. 39, 121 (1968).

Quenching of Rb Resonance Radiation by Nitrogen and the Rare Gases (with P. Davidovitz and J.A. Balliecio) J. Chem. Phys. 48, 2376, (1968).

High-speed Correlator (with B. B. Hooper, Jr.) Rev. Sci. Instr. 39, 864, (1968).

Project Director for N.S.F. Grant; (NSF. GY 4836, Instructional scientific grant).

LIST OF RESEARCHERS

MICHAEL CAIN, Born Boston, Mass., 1941. B.A. (English) Harvard, 1964; Poetry published 1962, *Locus Solus*. B.F.A., M.F.A. (Painting), Yale, 1967.

PATRICK CLANCY, Born Hornell, N.Y. 1941. B.S. (Education) Pratt Institute, 1964; B.F.A., M.F.A. (Painting), Yale, 1967; Group Show, Jewish Community Center, 1966 (paintings and drawings). Group show, Athena Gallery, 1966 (Paintings and drawings)

WILLIAM CROSBY, Born New Haven, Conn., 1939. B.A. (Art History) American University, 1965. Yale School of Architecture, 1965. Group show, Addison Gallery, 1965 (Light and Sound Piece); Group show, Trenton Athenaeum, 1967 (Light and Sound Piece).

WILLIAM DUESING, Born Detroit Mich., 1942. B.A. (Art) Yale, 1964. Yale School of Architecture, 1965. Photograph exhibited Museum of Natural History, N.Y.C., Annual Show, 1968.

PAUL FUGE, Born Plainfield, N.J., 1946. B.A. (Psychology) Yale, 1968. Published articles in *Electronic's World* and *Popular Electronics*, 1965, 1966.

PETER KINDLMANN, Born Vienna, Austria, 1939. B.A. (Physics) Columbia, 1962; Kinne Humanities Award, 1960. M.S. (Physics), Yale, 1964; National Science Foundation predoctoral fellow (1962-1966); Ph.D. (Physics), Yale, 1966; Honeywell Award in Engineering and Applied Science (1966); Nine articles published in Scientific Journals. Research Applied Scientist in Engineering and Applied Science Department, Yale, 1966 to present.

DAVID RUMSEY, Born New York, N.Y., 1944. B.A. (Art) Yale, 1966; Ingram Merrill Grant for Film-making, 1966. B.F.A., M.F.A. (Film-making & Light-Sound Environment) Yale, 1969.

SKETCH OF BUDGET

(for research facilities only)

PHASE I $22,000

PHASE II $8,000

PHASE III $19,000

FACILITIES

In September we will occupy a complex of buildings in New Haven that will serve as studio, seminar room, and exhibition space. The facilities contain several large scale open interiors permitting flexibility regarding experimental installations.

Electronic Equipment and materials presently at our disposal for the proposed research:

Approximately 1500 specially prepared fluorescent bulbs capable of being fired in an electric field by amplified signals.

Approximately 50 sixty-watt-second strobe lights with associated trigger circuits and power supplies

Various other experimental light sources including electroluminescent panels, mercury vapor lamps, quartz iodide bulbs, phosphors and phosphorescent pigments, photochromic paper, infrared and ultraviolet lights, and a wide range of incandescent bulbs.

A set of modular stretched silver mylar panels used as reflectors, some of which are specially fabricated to serve as large scale electrostatic speakers or as oscillating parabolic mirrors activated by electronic signals.

Loudspeakers including 50 modular poly-planar; 5 Jensen bass guitar, 6 KLH Model 6, etc.

Ten two-track Magnacorder tape decks and associated stereo and monaural amplifiers, one Ampex studio console, three four track Sony stereo decks, one Wollensack monaural recorder, one Uher portable recorder.

Four Dynakit 60 watt amplifiers and preamplifiers, 50 Amperex 20 watt amplifiers, 12 specially fabricated power amplifiers, 6 high voltage amplifiers, etc.

Notch filter and pulse generator, 8 oscillators, 7 oscilloscopes.

A hybrid analogue-digital programming device, as described in accompaning technical report.

Our present electronic shop is highly inadequate, and as funds allow, the facilities will be improved. The Yale Electronic Shop has been at our disposal in the past on a part-time basis, an obvious limitation to the experimental nature of our work.

Additional equipment proposed for the forthcoming year:

One Nagra portable tape recorder
Senhauser ultradirectional and omnidirectional microphones.

Seven track Ampex studio portable tape recorder.

"PA" sound system facilities with high-watt-output amplifiers and speakers.

Laboratory Laser of the Helium-Neon or Argon types with associated prisms, mirrors and optical devices.

Tectronic Laboratory Oscilloscope.